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Mesosphere summer echoes observed with VHF and MF radars at Wakkanai, Japan (45.4°N)

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ABSTRACT

Mesosphere summer echoes (MSE) were observed during 2000–2001 and in 2009 with a 46.5-MHz VHF radar at Wakkanai, Japan (45.4°N). MSE at VHF (VHF-MSE) are active at 80–90 km altitudes in the daytime mainly during June–July. Echo layer thickness ranges from a few to about 5 km, and layer altitude and echo intensity are often modulated by short-period atmospheric gravity waves while the layer descends gradually at 0.2–0.8 m/s with time, maybe due to tides. Detailed analyses of three VHF-MSE events show that meridional winds at the MSE altitudes over Wakkanai observed with a collocated 1.96-MHz MF radar are equatorward, indicating that cold ice particles and/or irregularities are advected southward from higher latitudes. It is found that VHF-MSE are often accompanied by simultaneous MSE at MF (MF-MSE) from a common volume, suggesting that plasma turbulence and/or short-scale electron density structures are responsible for the generation of VHF- and MF-MSE.

1. Introduction

It is well-known that strong radar echoes return from the cold summer mesopause region at high latitudes. These echoes are now called polar mesosphere summer echoes (PMSE). PMSE have been studied mainly with VHF radars (hereafter called VHF-PMSE) located at northern and southern high latitudes (e.g. Ecklund and Balsley, 1981; Rapp and Lübken, 2004, and references therein; Morris et al., 2009). Mesospheric neutral air turbulence and heavy charged ice aerosol particles are believed to be important for the creation of PMSE (Rapp and Lübken, 2004). VHF radar echoes showing characteristics similar to PMSE have been observed at higher midlatitudes (52°–54°N) in Germany (e.g. Czechowsky et al., 1979; Reid et al., 1989; Latteck et al., 1999) and the UK (Thomas et al., 1992): these midlatitude echoes, mainly appearing at 80–90 km altitudes, are called mesosphere summer echoes (MSE). Though compared with VHF-PMSE, MSE at VHF (hereafter called VHF-MSE) exhibit rather rare occurrence and weak echo intensity, and appear only during the daytime when the D region electron density is high. VHF-MSE are believed to be also related to the cold mesopause temperature in summer, which causes noctilucent clouds (NLC) at midlatitudes (Taylor et al., 2002; Wickwar et al., 2002). Latitudinal and longitudinal extents of MSE/NLC regions and the lowest latitude of their occurrences remain to be determined. From 10-year observations of mesospheric echoes with the 46.5-MHz middle and upper atmosphere (MU) radar at Shigaraki, Japan (34.9°N, 136.1°E), Kubo et al. (1997) showed that daytime echoes are strongest at 80–85 km altitudes in summer, especially in July, in line with the above-described observations in Europe. Whether the summer echoes at Shigaraki are also related to low mesopause temperature or not is unknown. Mesosphere echoes in the summer daytime, not related to low mesopause temperature, have been also observed with VHF radars at tropical latitudes (e.g. Kumar et al., 2007; Lehmacher et al., 2007).

Occurrences of PMSE at MF (hereafter called MF-PMSE) are still controversial. Simultaneous observations with VHF and MF radars were used to detect PMSE at both frequency bands. Röttger (1994) noted simultaneous PMSE observations with the EISCAT 224-MHz VHF radar at Tromsø and an MF radar at Murmansk, about 800 km east of Tromsø. Using the EISCAT VHF radar and a collocated MF radar, Bremer et al. (1996) gave a strong hint that PMSE also occurred at MF. Liu et al. (2002) discussed possible relationships between PMSE from the EISCAT VHF radar and echoes at the MF band from a collocated dynasonde. On the other hand, Hoppe et al. (1990) reported no obvious relation between Tromsø MF radar echoes and PMSE simultaneously detected with the EISCAT VHF radar, and Ogawa et al. (2004) pointed out that when PMSE at HF and VHF were observed at distances beyond 180 km from the Tromsø MF radar, the MF radar detected no appreciable signatures of echo enhancement. Murphy and Vincent (2000) examined enhanced echo amplitudes detected in summer with an MF radar at Davis,

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Antarctica, to discuss potential use of the echo enhancement as a measure of PMSE. Jones and Davis (1998) analyzed statistically mesospheric echoes at MF on dynasonde ionograms from northern and southern high latitudes, and found that echo characteristics are different from those of PMSE and that there is no statistical evidence to suggest that echoes in summer are different from those in other seasons. Using an MF radar at Rothera, Antarctica, Jones et al. (2004) showed that though there exist some peaks in echo occurrence at altitudes of 80–85 km in summer, the statistical results suggest most of echo features to be unlikely linked to PMSE. Recently, Ramos et al. (2009) have presented clear examples showing that in Alaska, when VHF-PMSE are detected, PMSE are simultaneously observed at both MF and HF, though the MF, HF and VHF radars are not always collocated. To our knowledge, detection of midlatitude MSE at MF (hereafter called MF-MSE) has never been reported.

This paper presents midlatitude MSE observations at Wakkanai in Hokkaido, Japan (45.4°N, 141.8°E) with collocated VHF and MF radars, capable of probing a common volume over Wakkanai, during 2000–2002 and in 2009. Note that the latitude of Wakkanai is lower by 6°–9° than the latitudes of Kühlungsborn (54.1°N, 11.8°E) and Harz mountains (51.7°N, 10.5°E) in Germany and Aberystwyth (52.4°N, 4.1°W) in the UK where midlatitude VHF-MSE have been often observed (e.g. Czechowsky et al., 1979; Reid et al., 1989; Thomas et al., 1992; Latteck et al., 1999). After giving a brief summary of observational results from the Wakkanai VHF radar, we analyze in detail some MSE events to show that echo characteristics are similar to those observed in Europe and that VHF-MSE are often accompanied by MF-MSE.

2. Instrumentation

The main technical parameters of the Wakkanai VHF (mesospheric mode) and MF radars are summarized in Table 1 (e.g. Igarashi et al., 2000; Murayama et al., 2000). The 46.5-MHz VHF radar equipped with 144 three-element Yagis for transmission and reception has a peak power of 80 kW and an antenna beam width of 6° in the vertical. For reception, the antenna array is divided into six subarrays. This radar is designed to operate in spaced antenna (SA), Doppler beam swinging (DBS), meteor and mesospheric modes: the SA and DBS modes are used for troposphere observations but not for mesosphere ones. For mesosphere observations, the time resolution is 3 min. The number of coherent integrations (70), pulse coding (no coding) and sampling interval (2 km–identical to the pulse width) in 2000 differ from those (80, 8-bit complementary code and 600 m, respectively) in the other years. Because of these differences, direct comparison between echo intensity in 2000 and that in the other years is impossible.

The collocated 1.96-MHz MF radar with a peak power of 50 kW is equipped with four crossed-dipole antennas for transmission and reception. The antenna beam width is about 40° in the vertical. The time resolution is 4 or 6 min depending on the year. The half-power pulse width is 48 μs giving a range resolution of ~7 km. By oversampling in range, the sampling interval is set to 2 km. Horizontal winds are derived by using the conventional full correlation analysis method. Both the radars observe echoes from a common volume over Wakkanai. MF radar observations started in September 1996, while mesosphere observations with the VHF radar started on 7 July 2000, stopped on 18 July 2002 and resumed on 10 June 2009, which means that observations for all summer months were made only in 2001.

Table 1
Main technical parameters of the Wakkanai VHF and MF radars in 2000–2002 and 2009.

Parameter	VHF radar (mesospheric mode)	MF radar
Frequency	46.5 MHz	1.96 MHz
Peak power	80 kW	50 kW
Number of coherent integrations	70 (2000) 80 (2001, 2002, 2009)	–
Pulse shape	Gaussian	–
Pulse coding	no coding (2000) 8-bit complementary code (2001, 2002, 2009)	–
Antenna	144 (12 × 12) Yagis (6 subgroups)	4 crossed-dipoles
Effective antenna area	2581 m^2	–
Antenna beam width	6°	~40°
Antenna beam direction	vertical	vertical
Sampling interval/pulse width	2 km (2000) 600 m (2001, 2002, 2009)	2 km/48 μs
Time resolution	3 min	4 min (2000–2002) 6 min (2009)

3. Observations and data analysis

3.1. Summary of VHF-MSE events

From a close inspection of the archived VHF radar data we found many VHF-MSE events only in the daytime. The day (in Japan Standard Time; JST=UT+9 h) on which MSE were observed is called "event day" here. We categorized echoes as MSE when the echoes had backscattered signal-to-noise ratios (SNR) beyond 0 dB at least for 10 min on altitude-time plots of SNR variations, irrespective of year. As noted above, the observation parameters (number of coherent integrations, pulse coding and sampling interval) in 2000 do not coincide with those in the other years, indicating that the MSE detection is biased in 2000. We cannot estimate how this bias affects our results.

Fig. 1 displays VHF-MSE event days (marked by the black and gray rectangles) during May–August in 2000–2002 and 2009. As stated above, no mesosphere observations were made on the days marked as "No Observations". Unpredictable, high day-to-day variations in the MSE occurrences are discernible. The number of the event days is 19 during 8 July–28 August 2000, 30 during 8 May–26 July 2001, 0 in 2002, and 23 during 11 June–2 August 2009. No VHF-MSE events in 2002 are a little surprising: possible reasons are discussed in Section 4. In Fig. 1 MSE appearing on the days marked by black exist mainly at 80–90 km altitudes and between the middle of May and the beginning of August. MSE during 14–22 May 2001 are short-lived (~30 min) and have weak echo intensity. MSE marked by gray appear at 70–80 km after 2 August in 2000 and on 8 May 2001. Such lower altitude MSE were also observed by, for example, Czechowsky et al. (1979) and are not discussed here because of our interest in MSE at higher altitudes of 80–90 km. Thus, our observations indicate that MSE at 80–90 km are active mainly during June–July, in line with the result of Zecha et al. (2003) who made VHF radar observations at Kühlungsborn in 1998, 2000 and 2001 to find that the mean starting and last days of MSE events at 78.5–92 km were 3 June and 14 August, respectively (see also Bremer et al., 2006). Using 4-year data from VHF radar at Aberystwyth, Thomas et al. (1996) pointed out that echoes were observed at 66–84 km altitudes in all seasons but that stronger echoes and echoes above 85 km altitudes appeared largely in the summer months of May–August.